SCIENCE, AERONAUTICS, AND TECHNOLOGY

FISCAL YEAR 2000 ESTIMATES

BUDGET SUMMARY

OFFICE OF AERO-SPACE TECHNOLOGY — **ADVANCED SPACE TRANSPORTATION TECHNOLOGY**

SUMMARY OF RESOURCES REQUIREMENTS

	FY 1998 OPLAN 9/29/98	FY 1999 OPLAN 12/22/98	FY 2000 PRES BUDGET
	(Thousands of Dollars)		
X-33 Advanced Technology Demonstrator	318,300	277,300	111,600
[Stennis Space Center Test Stand Modification CoF]	[3,700]	[--]	[--]
X-34 Technology Demonstration Program	26,700	35,500	25,500
Future-X Demonstration Program	--	36,000	31,300
Future Space Launch Studies	10,000	30,000	30,000
Advanced Space Transportation Program (ASTP)	62,100	50,800	55,600
Total	417,100	429,600	254,000

Distribution of Program Amount by Installation			
Johnson Space Center	4,757	1,745	934
Kennedy Space Center	668	1,036	900
Marshall Space Flight Center	325,935	321,248	207,106
Stennis Space Center	16,990	30,340	1,269
Ames Research Center	12,258	10,156	7,605
Dryden Flight Research Center	6,230	7,413	3,093
Langley Research Center	13,958	22,650	13,546
Glenn Research Center	11,500	11,636	8,567
Goddard Space Flight Center	1,080	40	30
Jet Propulsion Laboratory	9,046	4,166	1,646
Headquarters	14,678	19,170	9,304
Total	417,100	429,600	254,000

ADVANCED SPACE TRANSPORTATION TECHNOLOGY

PROGRAM GOALS

The goal of Advanced Space Transportation Technology is to develop and demonstrate new technologies aimed at revitalizing access to space and in-space transportation. These new technologies are targeted to dramatically reduce launch costs, increase the safety and reliability of current and next generation launch vehicles, and significantly improve the technical performance of in-space transportation systems to reduce the cost of NASA's science and exploration programs and enable new, more challenging, missions.

STRATEGY FOR ACHIEVING GOALS

NASA's primary space transportation technology role is to develop and demonstrate pre-competitive, next-generation technology that will enable the commercial development of truly affordable and reliable space transportation systems – the third pillar for success of the Aero-Space Technology Enterprise. Success in this challenging endeavor would enable the U.S. to recapture worldwide commercial space markets, while dramatically improving transportation capabilities for civil missions and sustaining military missions. Consistent with the National Space Transportation Policy, NASA, as a member of the national team, will develop technology for the next generation of reusable space transportation systems, with a target of reducing launch and space transfer vehicle development and operations costs dramatically in the next decade. NASA will also support DoD in developing and demonstrating technologies which support Evolved Expendable Launch Vehicle and Military Spaceplane objectives, as well as participate in the government/industry Integrated High Payoff Rocket Propulsion Technology (IHPRPT) initiative.

Advanced Space Transportation Technology has three primary components: Reusable Launch Vehicle (RLV), the Advanced Space Transportation Program (ASTP) and Future Space Launch Studies. Incorporating innovative partnerships with industry, other agencies and academia, the RLV and ASTP programs encompass the flight and ground demonstration of advanced and enabling technologies required to revolutionize space access. The combined program ranges from the exploratory research of high pay-off emerging technologies, taking advantage of aeronautics investments as appropriate, to the flight demonstration of advanced technologies by X-Vehicles. Requirements for these technology investments will be defined in cooperation with other NASA enterprises, the Department of Defense (DoD), and commercial industry.

The Future Space Launch Studies are industry-led studies to develop options and roadmaps in support of future decisions on space transportation architecture elements, which will significantly reduce NASA's launch costs. In the near term, X-vehicle ground and flight demonstrations, RLV business planning, and the Future Space Launch Studies will provide the basis for an end-of-the-decade decision, as called for in the 1994 National Space Transportation Policy, on an appropriate strategy for significantly reducing NASA's launch costs. The studies will also inform decisions to be made in FY 2000 on the pursuit of a Crew Return Vehicle (CRV) for the International Space Station. In preparation for these decisions, the Administration has included over $1 billion in the Future Space Launch Development budget line between FY 2001 and FY 2004 to support activities to be undertaken in accordance with the recommendations resulting from the Future Space Launch Studies.

Reusable Launch Vehicle (RLV)

The RLV program includes systems engineering and concept analysis, ground-based technology development, and a series of flight demonstrators: the X-33 Advanced Technology Demonstrator, the X-34 Technology Testbed demonstrator, and Future-X Pathfinders. In FY 1999 and FY 2000, the RLV program will consist of the X-33, X-34 and recently selected Future-X Pathfinder projects. Each part of these programs contribute to validating key component technologies, proving that they can be integrated into functional vehicles and demonstrating low-cost operations in relevant flight environments. These programs build on the technologies being developed in the Advanced Space Transportation Program and are limited to technologies that require flight demonstration

X-33 Program

The X-33 objective is to demonstrate technologies and operations concepts with the goal of reducing space transportation costs to one tenth of their current level. The X-33 program includes two major decision points. The first, whether to proceed with Phase II, was completed in July 1996 and was made based on specific programmatic, business planning, and technical criteria which had previously been agreed upon by NASA, the Office of Management and Budget and the Office of Science and Technology Policy. NASA selected the Lockheed Martin Skunkworks to lead an industry team to develop and fly the X-33. First flight of the vehicle is now planned for July 2000. The second decision will be made after X-33 ground and flight tests, when government and industry will consider whether to pursue in Phase III the private financing of the development and operations of a full-scale operational RLV. At that point, if the industry partners and investment community are not satisfied that the technological risk is low enough to proceed, NASA could pursue other options, including the possibility of continued RLV technology work to accomplish further risk reduction. For example, the X-33 may require technology enhancements, or a follow-on vehicle to the X-33 may be needed to prove ultimate feasibility.

NASA is utilizing an innovative management strategy for the X-33 program, based on industry-led cooperative agreements. As a result of industry's leadership of the program, the participants are not playing traditional roles, with government overseeing and directing the work of the industry contractors. Instead, government participants are acting as partners and subcontractors, performing tasks for industry because industry believes that these government team members offer the most effective means to accomplish the program objectives. The government participants report costs and manpower to the industry team leader as would any other subcontractor. The industry-led cooperative arrangement allows a much leaner management structure, lower program overhead costs, and increased management efficiency.

The X-33 is an integrated technology effort to flight-demonstrate key Single Stage To Orbit (SSTO) technologies, and deliver advancements in: 1) ground and flight operations techniques that will substantially reduce operations costs for an RLV; 2) lighter, reusable cryogenic tanks; 3) lightweight, low-cost composite structures; 4) advanced Thermal Protection Systems to reduce maintenance; 5) propulsion and vehicle integration; and 6) application of New Millennium microelectronics for vastly improved reliability and vehicle health management. X-33 will combine its results with the successes of the DC-XA, X-34 and complementary ground technology advances to reduce the technical risk of full-scale development of an operational RLV. The X-33 test vehicle will fly 13-15 times the speed of sound and will test the boundaries of current technology. Together, the DC-XA, X-34, and X-33 will provide a number of flight tests of key technology demonstrations prior to the decision to privately finance the development and operations of the next generation RLV system.

The X-33 Program is also funding refurbishment of the test complex infrastructure at the Stennis Space Center (SSC). The B-2 test stand required $3.7 million in FY1998 appropriations, and the A-1 test stand required $5.5 million of FY 1999 appropriations. The test complex infrastructure support requirements relative to X-33 for FY 2000 and beyond (if any) are to be defined in appropriate Task Agreements with industry and incorporated into the X-33 cooperative agreement.

It is envisioned that private industry will have a primary role in the funding, development, and operation of a next-generation launch system. Therefore, business venture plans are as critical to the RLV program as any technical advancements made on the experimental vehicles. Programmatic and business plans for an operational commercial RLV, expressed in innovative industry-developed and -led business plans, will receive equal consideration with technology demonstrations in future decisions on developing an operational launch vehicle. These plans will address policy and legislative issues as well as private financing options, and will inform the Future Space Launch Studies.

X-34

The X-34 program will demonstrate technologies necessary for a reusable vehicle, but will not be a commercially viable vehicle itself. It will be a rocket-powered, Mach-8-capable flight demonstrator test bed to close the performance gap between the subsonic DC-XA and the Mach 13+ X-33. The X-34 objective is to enhance U.S. commercial space launch competitiveness through the development and demonstration of key technologies applicable to future, low-cost reusable launch vehicles. The X-34, now planned to fly for the first time in late 1999, will demonstrate flexible integration capability, high flight rate (25 flights per year), autonomous flight operations, safe abort capability, and a recurring flight cost of $500,000 or less. The X-34 program is procuring two flight vehicles, in keeping with the usual practice in X-vehicle programs, to ensure that the program meets its objectives without constraining the aggressiveness of the demonstration effort.

The 50-month, fixed-price X-34 contract is being conducted by Orbital Sciences Corp. of Dulles, Virginia. NASA's Ames, Langley, Dryden, Marshall, Kennedy and White Sands complexes and Holloman Air Force Base are all involved in the program. The government's work responsibilities include primary propulsion development, thermal protection system integration, wind tunnel support, and testing and flight operations.

After completion of the first flight series (the basic contract includes two flights), the X-34 program is planning a second phase for additional flight testing of up to 25 flights in one year. These flights will demonstrate key embedded technologies and systems operations, as well as additional technology experiments and test articles from the RLV and Advanced Space Transportation programs. X-34 modifications and experiments will benefit from being comparatively small, thereby lowering the expense and risk of demonstrating the technologies, and making their integration into the vehicle less costly. The low-cost X-34 demonstrator will increase the scope and aggressiveness of flight demonstrations, thus increasing the return to the RLV program.

Future-X Pathfinder

As part of NASA's core mission to advance the state-of-the-art in aeronautics and space transportation, the Agency will continue to develop and demonstrate advanced technologies through the use of experimental flight vehicles. The primary objective of this "Future X" program is to flight demonstrate technologies which can dramatically reduce the cost and increase the reliability of reusable space launch and orbital transportation systems. Future-X Pathfinder demonstrations build on ASTP technologies by carrying out small-scale flight demonstrations every 12-24 months. Pathfinder projects demonstrate cutting-edge technologies with high payoff potential and cost between $1M and $100M.

NASA recently selected proposals and began funding new Pathfinder-class demonstrations in FY 1999. One new Pathfinder demonstrator and seven flight experiments were selected for initiation in FY 1999. Those projects are under negotiation, and project details will be provided at a later time. These selections will enable NASA to continue pushing the state of the art in launch vehicles by demonstrating technologies that are one generation beyond those contained in the X-33 and X-34 demonstrators. The selected Pathfinders include:

- a modular orbital flight testbed called the Advanced Technology Vehicle (ATV), an experimental vehicle to be flown in both orbital and reentry environments.
- a Hall-effect Solar Electric Thruster system flight demonstration of new onboard in-space propulsion technologies;
- an experiment to demonstrate an onboard intelligent planning system for autonomous abort;
- an experiment to demonstrate technologies that will significantly reduce the access-to-space costs of small payloads;
- an experiment to demonstrate advanced technologies of an integrated vehicle health management system;
- an experiment to demonstrate ultra-high temperature ceramics for reusable, sharp hypersonic leading edges;
- an experiment to demonstrate propulsion technologies that will reduce the weight and size of advanced cryogenic upper stages;
- an experiment to demonstrate advanced in-space propulsion technologies using an electrodynamic tether.

Advanced Space Transportation Program (ASTP)

ASTP is the technology base program for space transportation. Future revolutionary advances in space transportation technology will be developed in this program to reduce costs and increase reliability and performance across the entire mission spectrum. Advanced technologies will be developed and ground-tested to bring them to readiness levels where they can either be adopted by industry, or if necessary, flight-proven in the RLV technology program. The ASTP will focus on technological advances with the potential to reduce launch costs beyond X-33 and Pathfinder demonstrators -- aiming at a cost-to-orbit measured in hundreds, not thousands, of dollars per pound, in accordance with Aero-Space Technology Enterprise Goal 9. In addition, ASTP will make key technology investments for in-space transportation systems to reduce costs, system mass and trip time for future in-space missions in accordance with OAT Goal 10.

The ASTP has been restructured to form focused, core and research investment areas.

- Focused projects have a strong technology pull based on near-term operational system development needs. The current focused projects support the next-generation reusable launch vehicle (RLV), small payload launch, and in-space transportation systems. Core projects push the state of the art in propulsion and airframe systems towards the long-term program goals.
- Core technology priorities are derived from the contribution of each technology to overall transportation system objectives.
- The space transportation research concentrates on very advanced, breakthrough concepts for revolutionizing space travel.

The ASTP program is utilizing competitive technology selection and procurement processes wherever feasible in order to maximize the involvement of the myriad traditional sources of space transportation technology throughout the country, as well as to bring in potential new sources. An inter-center process has been established to prioritize ASTP technology investments based on their system payoff in terms of improvements in mission capability, cost, reliability, operability, responsiveness, and safety. The goals, objectives, and progress of the ASTP will be evaluated on a yearly basis by a panel of nationally recognized experts to ensure program content is consistent with government and industry priorities, and that the program is yielding the maximum possible return on the taxpayers' investment.

Focused Projects

The **RLV Focused** project will pursue investments in airframe systems and propulsion technologies consistent with goals of the X-33 and Pathfinder programs: to reduce the cost of access to space to $1000/lb in ten years by enabling the full-scale development of an operational RLV shortly after the turn of the century. Funding supports RLV Focused tasks that are complementary to, but do not duplicate, the work funded by X-33. Technology tasks are selected competitively, and are not limited to support of the VentureStar concept, but are applicable to any viable next-generation RLV concept. Technology development has been initiated for durable thermal protection systems, lightweight conformal structures, increased component life capability, low-cost manufacturing, lightweight airframe and propulsion components and advanced power systems.

The **Small-Payload Focused (Bantam)** project has been restructured to develop advanced reusable technologies applicable to systems capable of launching small science and technology payloads. The new goal of the project is to mature and demonstrate unique technologies that will enable the development of a reusable launch system to launch 200- to-300-pound payloads for $1.0M to $1.5 million per flight in the 2004-2005 time frame. A large number of the technologies required to meet this goal also have application to other payload classes and are funded in the Core Airframe and Core Propulsion budget lines. Concepts under study to achieve this goal include multistage rockets, airbreathing combined-cycle vehicles, beamed-energy laser-powered vehicles, and a variety of innovative launch-assisted concepts. Funding supports a phased approach where (1) critical enabling technologies are matured to support concept selection, (2) core reusable technologies that have application to multiple small-payload launch and larger RLV concepts are accelerated, and (3) the most promising technologies are matured toward flight demonstration within the Future-X Pathfinder program. The project is expected to culminate with a potential Future-X flight demonstration of the most promising vehicle concept in the 2002-2004 time frame.

The **Hybrid Propulsion Focused** project is being conducted under a Cooperative Agreement between NASA, DoD and U.S. industry, with the objective of demonstrating hybrid (solid fuel, liquid oxidizer) propulsion technology to enable U.S. industry to commercialize hybrid boosters for space launch operations. Hybrid motors offer potential for safer, lower cost, and environmentally friendlier boosters for U.S. launch providers. This resource-shared (experts, facilities and dollars) and jointly-managed program will demonstrate full-size, flight-like boosters on a schedule suitable for application on operational launch systems early in the 21st century. The program will accomplish ground test firings of both upper-stage–scale, 10,000-pound-thrust motors and booster-scale 250,000-pound-thrust motors, and is designed to allow rapid development of flight hardware with minimum risk.

The **NSTAR Focused** project supports the design and ground testing of the NASA Solar electric propulsion Technology Application Readiness (NSTAR) ion engine launched on the New Millennium DS-1 spacecraft in October 1998. NSTAR has validated ion propulsion for future robotic planetary missions, as a step toward meeting OAT Goal 10.

The **In-Space Focused** project will pursue technology investments to reduce costs, spacecraft system mass and trip time for future space missions in accordance with Aero-Space Technology Enterprise Goal 10. The project will support technology work in the areas of:: advanced solar-electric and solar-thermal propulsion systems for Earth orbit and planetary transfer; atmosphere-assisted entry for planetary missions and Earth-orbit return; cryogenic fluid management for orbit transfer and exploration missions; and non-conventional transportation systems, such as electrodynamic tethers.

Core Technology

The **Core Propulsion** technology project is pursuing the maturation of advanced, highly reusable technologies, significantly beyond the current state of the art (X-33 for reusable launch vehicles and NSTAR for in-space transportation systems). The technologies currently being pursued focus on air-breathing rocket-based combined cycles (RBCC). Future technology investments will focus on advanced materials to reduce weight and improve engine life, advanced nozzles to improve performance, and turbomachinery technologies to improve reliability and engine life. The aim is to mature propulsion technologies through ground testing and analyses to the point where they can be considered for a Future X-vehicle flight evaluation. Three RBCC concepts were selected in FY 1996 for preliminary proof-of-concept ground demonstration. These demonstrations will lead to a decision in FY 1999 - 2000 on whether or not to proceed with further development of a flight demonstration project. Propulsion technologies will be addressed in partnership with NASA Aeronautics Centers, DoD and industry to assure maximum synergy between aeronautics research and the systems design and application to space launch.

The **Core Airframe** project is pursuing the maturation of advanced, highly reusable airframe and structures technologies significantly beyond the current state of the art for reusable launch vehicles (represented by the X-33). Airframe systems technologies include structures and materials, cryogenic tanks, thermal protection systems (TPS), avionics/operations, and system analysis, design and integration. Technology investments are just beginning in**:** advanced composites and refractory composite hot structures development**;** technologies for both structure and cryotank joints**;** ultra-high-temperature ceramic thermal protection materials**;** instrumentation for vehicle health monitoring**;** and highly reliable avionics systems. The aim is to mature these technologies through ground testing and analyses to the point where they can be considered for a Future X-vehicle flight evaluation. Airframe systems technologies will be addressed in partnership with NASA Aeronautics Centers, DoD and industry to assure maximum synergy between aeronautics research and the systems design and application to space launch.

Space Transportation Research

The **Space Transportation Research** provides the basic research function of the ASTP program. The activity focuses on advanced concepts for enabling breakthroughs in space transportation, maturing these revolutionary ideas via small, critical technology experiments and breadboard validations. This effort relies on partnerships with industry, universities, other agencies and NASA centers to identify longer term technologies with tremendous promise for performance improvement and cost reduction. Areas of interest include advanced concepts for launch augmentation, pulse detonation engines, high-energy propellants, and high-energy concepts and materials which hold promise for enabling exciting new missions that are beyond the realm of present technological capability. The research project is guided by a peer review process involving National experts in the applicable technical fields.

<u>SCHEDULE & OUTPUTS</u>

Reusable Launch Vehicle (RLV)

X-33 Critical Design Review. Plan: July 1997 Actual: October 1997	The second key review milestone, which closed the vehicle design for production, validated readiness of the vehicle technologies, and defined schedule to first flight. Delayed to solve issues of weight growth and flight stability/controllability.
X-33 EIS Record of Decision Plan: October 1997 Actual: November 1997	EIS Record of Decision allowed launch site construction to begin. Mitigated several flight safety and environmental issues.
X-33 LO_2 Tank Delivery Plan: December 1997 Actual: February 1998	Completes design, manufacture, test and delivery. Delay had no impact.

X-33 LH_2 Tank Delivery Plan: June 1998 Revised: March 1999	Completes design, manufacture, test and delivery to MSFC. Delayed because of tank redesign activities and issues with main joint fabrication/testing. LH_2 tank delay is a major factor in X-33 first flight slip from July 1999 to July 2000.
First X-33 Aerospike Engine Test (Powerpack) Plan: March 1998 Actual: September 1998	First complete J2-Aerospike test. Supports first flight-unit engine scheduled for delivery. Late delivery of the engine was due to manufacturing difficulties with the expansion ramps and turbomachinery. Engine delay is a major factor in X-33 first flight slip from July 1999 to July 2000.
X-33 Thermal Protection System Delivery Plan: August 1998 Revised: December 1999	Delivery of complete Thermal Protection System for X-33 flight demonstrator. Delayed due to delay in delivery of LH_2 tank.
X-33 Vehicle to Roll out Plan: May 1999 Revised: January 2000	X-33 flight demonstrator vehicle rollout enabling final checkout. Delayed due to LH_2 tank and aerospike engine delays..
X-33 First Flight Plan: July 1999 Revised: July 2000	The flight test program, based at Edwards Air Force Base, will fly at speeds greater than Mach 13. Delayed due to LH_2 tank and engine delays and reassessment of schedule between roll-out and first flight.
X-34 Engine Delivery Plan: December 1998 Revised: June 1999	Completes design, manufacture, test and delivery. Engine was delayed due to technical problems but is not on the critical path to first flight.
X-34 First Flight Plan: March 1999 Revised: September 1999	The flight test program will expand in increments to assure success. Delayed due to failures in the ground test RP-1 composite tank that delayed start of fabrication of the first flight tank and due to a processing accident in the manufacture resulting in scrapping of the flight wing lower surface. Both problems have been corrected.
X-34 First Powered Flight Plan: August 1999 Revised: December 1999	The flight program will expand the flight profile with initial, unpowered flights to be followed by powered flights that will reach Mach 8. Delayed due to delays in vehicle fabrication, specifically the composite tank and flight wing.

Advanced Space Transportation Program (ASTP)

Begin Bantam Cycle I contracts Plan: July1997 Actual: December 1997	Four contractors began detailed system studies of low-cost vehicle concepts and enabling technologies. Delayed due to protest by a losing proposer. None of the resulting concepts met the program cost-per-flight goals, leading to restructuring of the program
NSTAR delivery for DS-1 launch Plan: January 1998 Actual: March 1998	Hardware delivered for integration onto spacecraft. Launch of DS-1 occurred on October 24th, three months late, due primarily to spacecraft technical and testing problems. NSTAR ion propulsion system is providing primary propulsion for the mission, and has met minimum mission success/technology validation criteria.
Ground Test First Hybrid 250K Pressure-Fed Motor. Plan: March 1998 Revised: March 1999	Test program was transferred to the Stennis Space Center. Two test motors are ready and awaiting test facility activation. Delayed due to slip in component deliveries
RBCC component-level test completion (Mach 0-4). Plan: May 1998 Revised: September 1998	Ground test of critical low-speed air-breathing, rocket-based combined cycle (RBCC) engine technologies such as inlet design and low-speed air augmentation. Injector, inlet and ignition system test complete. Thruster and low-speed air augmentation test delayed due to test anomalies and scheduling difficulties.
Begin mission profile testing of NSTAR engine Plan: March 1998 Actual: October 1998	Test back-up flight hardware, gather and analyze flight data, and resolve unforeseen flight anomalies. An anomaly in initial NSTAR operation was resolved, in part, through ground test/verification of the failure mode.
Complete RBCC engine testing Plan: August 1998 Revised: September 1999	Integrated engine testing essential to predict propulsion system performance. Facility problems, scheduling difficulties and upgrades to the engine to improve performance based on recently acquired test results have resulted in a revised date.
Complete 500-hour test of 10 kW Hall electric thruster Plan: June 1999 Actual:	First demonstration/validation of high-power electric thruster
Conduct CDR on ProSEDS Plan: August1999	Propulsive Small Expendable Deployer System (ProSEDS) tether flight experiment scheduled for Critical Design Review.

Initiate Breakthrough Propulsion Physics Experiments. Plan: April 1999	Award Breakthrough Physics experiments under NASA Research Announcement.
Complete design of flight-weight RBCC engine Plan: March 1999 Revised: September 2000	Integrated performance and weight model of operational RBCC vehicle. Could lead to flight-weight engine development if justified by system payoff. Budget reductions due to Agency priorities have delayed this activity.
Ground Test First Hybrid 250K Pump-Fed Motor Plan: March 2000	Modifications of the SSC E1 test stand for pump-fed hybrid motor tests are now being designed. The two pressure-fed test motors will be refurbished to support these tests.
Complete RLV focused technologies tasks Plan: September 2000	Both airframe and propulsion RLV Focused technology activity results available
NSTAR Engine ground demonstration Plan: January 2000	Complete ground demonstration of 100 % design life on the NSTAR ion engine
Complete Small Payload focused technologies and select concepts Plan: September 2000	Concepts will be selected for flight demonstration of a reusable first stage based on FY 1999 and FY 2000 technology development.

ACCOMPLISHMENTS AND PLANS

Reusable Launch Vehicle

X-33

The X-33 program met several critical milestones in FY 1998, including: completion of the vehicle Critical Design Review; initiation of X-33 flight test vehicle assembly; integration of the liquid oxygen tank into the X-33 final assembly fixture; initiation of the two composite liquid hydrogen tank assemblies; and initiation of the powerpack testing at the Stennis Space Center. Initial qualification testing on the thermal protection systems was completed and verified performance of the design. The fourth-unit build of the avionics and software systems was delivered and integration testing initiated, including antenna testing. In FY 1999, the software build and test will continue and all Global Positioning Satellite interface testing will be completed. Assembly and testing of the X-33 will continue in FY 1999, with completion of final integration scheduled in early FY 2000.

The second cycle of design and business planning for the operational Reusable Launch Vehicle, VentureStar, is well underway. A systems design review for VentureStar is to be held in FY 1999 that will provide the basis for Preliminary Design of the VentureStar flight vehicle. Market analyses and RLV capitalization planning for VentureStar was completed in FY 1999, indicating substantial capture of international payload markets and several potential financing options to permit capitalizing commercial development and operations for VentureStar.

In FY 2000, the final assembly of the X-33 will be completed, systems testing and flight testing will be conducted. The information gathered from the X-33 testing and the ground technology program will enable an industry decision on whether to proceed with the development of the VentureStar.

As indicated above, the X-33 program has encountered technical problems, which have resulted in a slip to the schedule of approximately one year since the FY 1999 budget to Congress. However, the government's funding responsibilities under the cooperative agreement are fixed, thus no additional funding will be required, despite the technical issues and delays.

<u>X-34</u>

The X-34 project completed several critical milestones in FY 1998, including:

1. Negotiated and defined the X-34 Characterization and Validation contract modification, which provided: a second flight vehicle for the program, early validation of critical X-34 systems, an unpowered flight prior to powered flight operations, and a gradual expansion of the flight test envelope.
2. Completed build-up of the first (A-1) fuselage, and completed vehicle static load testing.
3. Completed static load testing of the first flight wing, and delivered the wing for vehicle integration.
4. Completed development of the X-34 Main Propulsion System by an in-house MSFC team.
5. Completed the detailed design review of the vehicle Thermal Protection System.
6. Completed testing of the LOX qualification tank.
7. Completed low–speed, in-flight testing of the vehicle avionics at Holloman Air Force Base.
8. Procured through JSC and delivered the first flight set of GFE Main Landing Gear, and procured the second flight set of GFE Main Landing Gear.
9. Supported and participated in an Office of Safety and Mission Assurance-led review of the X-34 program. The review found the X-34 S&MA programs and processes to be satisfactory and appropriate.
10. Began build-up of the second (A-2) fuselage, with upper and lower panels completed, and the forward LOX tank integrated
11. Selected a set of seven TA-2 experiments that will fly on the X-34 vehicle to evaluate new Reusable Launch Vehicle technologies.

12. Began environmental assessment activities for East Coast flight operations by conducting initial program briefings to abort site leaders and key personnel.
13. Established a strong program emphasis on schedule with the prime contractor, despite the fact they do not have a strong schedule incentive due the fixed-price nature of the contract.
14. Established new policies placing responsibility for resolving issues between the prime contractor and government Task Agreement managers with the prime contractor. This has resulted in the prime contractor stepping up to their managerial responsibilities with their government "subcontractors."
15. Exercised the Optional Flight Test Program to conduct a total of 27 flight tests of the X-34 vehicle at White Sands Missile Range and the Kennedy Space Center/Eastern Range.

In FY 1999, the A-1 vehicle will undergo ground vibration testing and captive-carry FAA certification flights at DFRC and Edwards AFB, CA. The A-2 vehicle will be delivered to Holloman AFB for final preparations for, and execution of, the first flight of the X-34 vehicle, an unpowered flight with a landing at the White Sands Space Harbor. In FY 2000, the A-2 vehicle will be installed on the horizontal test stand at Holloman AFB for a full-up, integrated hot fire of the main propulsion system and Fastrac engine. After a successful static test, the vehicle will be prepped and is scheduled to execute its first powered flight over the White Sands Missile Range in December. FY 2000 will mark the beginning of the X-34 extended flight test program. The purpose of this extended test program is three fold: 1) Expand the performance envelope of the vehicle to Mach 8; 2) Demonstrate low cost, high-rate operability; and 3) fly a number of hosted experiments. The project will move from White Sands Missile Range to the Eastern Range to accomplish the remainder of the flights. During this time frame, the flight experiments will be integrated and flown. The second flight vehicle will also be delivered during this year.

As indicated above, the X-34 schedule has slipped approximately six months since the FY 1999 budget to Congress. However, the X-34 contract is fixed-price; therefore, no additional government funding is required.

Future-X Pathfinders:

In FY 1999, the RLV Program initiated the next generation of technology flight demonstration through the selection, announced in December 1998, of a new Advanced Technology Vehicle (ATV) and seven experiments. Final agreements will be negotiated and work initiated on these projects in FY 1999. Upon successful completion of negotiations with Boeing, the industry partner in the pending ATV cooperative agreement, the ATV design effort will begin in earnest. Also during FY1999, the X-40A vehicle, which has been part of an Air Force-sponsored flight test program, will be prepared for unpowered approach and landing tests as part of the ATV program. In FY 2000, the ATV will pass its critical design review, and fabrication of the flight vehicle will begin. Also, approach and landing tests of the X-40A will begin at Edwards AFB in FY2000.

Advanced Space Transportation Program (ASTP)

RLV Focused technologies were competitively selected in FY 1998 under NRA 8-21, Cycle 1, to support the decision to begin development of a next generation RLV. Selected technologies include: electron beam curing of polymer matrix composite tanks; composite joining technologies; integrated cryogenic tank and thermal protection system (TPS) hot structure; light-weight metallic

TPS concepts and their fabrication; durable blanket TPS; high-temperature, integrated structures; advanced proton exchange membrane (PEM) fuel cells; and lightweight, long-life thrust cell propulsion components. RLV Focused technology development will be completed in FY 2000 to support the decision to begin development of a next generation RLV. Electron beam composite curing, propellant densification, an advanced metallic TPS array, a PEM fuel cell prototype, and lightweight composite propulsion components will be demonstrated.

The Small Payload Focused (Bantam) project conducted a small payload launch conference that validated the need to reduce the cost of small payload launch capability. System preliminary designs of four concepts were completed. The projected launch cost using low-cost design methods and existing technology ranged from $4M to $5M -- confirming the need for advanced reusable technology development to enable the target cost of $1.5M per launch of 150 kg payloads. The Bantam project has been restructured to focus on advanced reusable technology development and system analysis leading to flight experiments as technology matures. Flight experiments will be conducted within the Pathfinder program. A significant portion of FY 1998 Bantam funding will be applied to FY 1999 due to the project restructuring. In FY 1998, several low-cost Bantam component technologies were successfully demonstrated. A low-cost turbopump was designed, fabricated and assembled that will reduce the Fastrac engine turbopump cost by a factor of three. Bench verification testing of a rocket engine controller based on a Chrysler automotive computer was completed. A modular propulsion avionics suite was delivered and is ready for bench testing. A PC-based launch control and mission planning system was demonstrated in bench tests. NASA continues to cooperate with the Air Force to develop a low-cost upper stage demonstration under the Bantam project using hydrogen peroxide and jet propellant (JP). Engine injector testing was initiated and compatibility tests are being conducted for hydrogen peroxide composite tanks.

In FY 1999 a large percentage of required Small Payload technologies are being funded under the Core Airframe and Core Propulsion investment areas because they are applicable to medium and heavy payload launch systems as well. Technology plans and roadmaps developed by an inter-Center team of experts in structures and materials, thermal protection systems, cryogenic tanks, propulsion, operations, and avionics and power systems will be implemented. Detailed system analysis of several promising small-payload launch concepts will be conducted and used to focus the technology development efforts. Enabling technologies for specific small-payload concepts will also be initiated.

In FY 2000, the results of these technology demonstrations and system level analyses of multiple concepts will support concept down-selection. Technologies that are concept specific will be completed and viable concepts will be selected for further focused technology development, including potential flight demonstration. Technology development that supports multiple concepts will continue toward completion in FY 2002.

Hybrid Focused technology development was de-scoped in FY 1998 to eliminate four pump-fed 250,000-pound-thrust (250K) motor tests. Following Congressional direction in FY 1999 pump-fed motor tests were re-instituted and the tests are now planned in FY 2000.

In FY 2000, all of the 250K motor testing is planned for accomplishment at the Stennis Space Center. In addition to the large scale 250K motor tests, subscale testing of peroxide hybrid motors is planned to develop the necessary design data needed for potential upper stage applications of hybrid technology for future Bantam missions. A large-scale sounding rocket demonstration is also planned at Wallops Flight Facility as a proof of concept leading to commercial application of hybrid technology to NASA's recurring sounding rocket missions.

The **NSTAR Focused Project** completed assembly and flight qualification testing of the NSTAR flight experiment and the flight unit was delivered. The launch of Deep Space 1 was accomplished in October 1998, and as of January 5, 1999, the engine technology has performed well, having produced thrust for over 850 hours in space, well beyond the 200-hour minimum success criterion. Life testing and anomaly resolution for the NSTAR flight experiment will continue throughout FY 1999, with anomaly resolution activities to be completed by the end of FY 2000.

The **In-Space Focused** technology project continued work on solar thermal propulsion technologies in FY 1998 that could lead to a flight demonstration. Structural dynamic testing in a flight environment simulation was completed for the full-scale inflatable solar concentrator. The secondary concentrator was manufactured and delivered by GRC. The solar thermal engine module was delivered. In addition, studies were completed to support applications for an electrodynamic tether propulsion concept. Work was initiated to design, develop and demonstrate critical solar-electric propulsion technologies. The design of an experimental high-power Hall-effect thruster has been completed and characterization will begin in FY 1999. Additionally, integration of a Russian-designed 1.5 kW Hall-effect thruster was completed. Delivery of an engineering-level 10-kW Hall-effect thruster will occur in FY 1999.

In FY 2000, high-power electric propulsion, long-term cryogenic propellant storage and non-toxic propulsion systems will continue to be pursued. Advanced concepts that utilize solar thermal energy, tethers and other off-board energy sources will also be pursued. Key electric propulsion technologies that will be examined include: long-life cathodes; power processing designs; propellant feed systems; and lightweight systems integration. Endurance testing of the engineering-level 10-kW Hall-effect thruster and breadboard designs of advanced power processing units will be completed.

Core Propulsion technology was focused on testing three air-breathing, rocket-based-combined-cycle concepts in FY 1998. The trajectory simulation facility at the General Applied Sciences Laboratory, Inc. (GASL) was completed and trajectory simulation mode was successfully tested for the first time in this country. Inlet tests on two RBCC concepts were completed at the GRC. Rocket thruster fabrication and testing was completed for two of three concepts. The third thruster concept has been delayed because of fabrication difficulty. Direct-connect testing was completed in RAM and SCRAM operating modes at GASL. Two RBCC concepts are currently installed in the GASL free jet facility. Testing on one concept is near completion. Testing on the second concept is beginning and will be completed in early FY 1999. Experimental studies at Pennsylvania State University and the University of Alabama, Huntsville are continuing in support of the engine concepts. A flight-weight RBCC propulsion system design will be conducted through FY 1999. Vehicle systems analysis will provide data to support a flight experiment decision by the end of FY 1999.

In FY 2000, the RBCC flight-weight engine design and vehicle system analysis will be completed. A decision to continue focused technology development toward a flight experimental vehicle will be made. Technology development for highly reusable propulsion systems will continue at a low funding level through FY 2000. Investments in advanced rocket propulsion technologies will support planned government/industry IHPRPT demonstrators and component technology developments to support the Small Payload Focused investment area. Technologies to be examined include: ceramic matrix composites for turbomachinery components and nozzles; metal matrix composites for housings and internal components; advanced altitude compensating nozzles; advanced fuels; analytical design and life prediction techniques. RBCC design and testing will continue towards flight weight designs and a low-cost development approach for long life propulsion systems will be pursued. Investments in advanced rocket propulsion technologies will continue in ceramic matrix composites for turbomachinery components and nozzles, metal matrix composites for housings and internal components, smart valves, and analytical design tools and life prediction techniques. A long life propulsion system will be demonstrated in FY2000.

Core Airframe technology development was initiated at a very low funding level in FY 1998. Limited investments were focused on structures and materials, cryogenic tanks, thermal protection systems, and avionics/operations technologies. Systems analysis has been initiated to support the evaluation of advanced air-breathing launch vehicle concepts to support the RBCC decision in FY 2000. In FY 1999, investments will continue in structures and materials, cryogenic tanks, thermal protection systems (TPS), avionics/operations, and system analysis, design and integration in support of the Small Payload focused investment area.

In FY 2000, development and demonstration areas in airframe systems will include: high-temperature, impact-resistant thermal protection systems; ultra-high-temperature leading edges; smart thermal protection systems; ultra-high temperature polymer matrix composites for airframes and propulsion systems; high-energy-density power systems; robust guidance, navigation and control systems; and advanced ground and range operations systems. The technologies are critical to the development of a low-cost small and medium/heavy reusable launch capability. Technologies will support potential flight demonstrations in FY 2002.

In the **Space Transportation Research** program, feasibility issues associated with revolutionary propulsion concepts continue to be evaluated at MSFC, GRC and JPL in cooperation with other federal agencies. The antimatter-triggered fusion research has continued to show progress towards the eventual objective of trapping, cooling and transporting antiprotons from Fermi Labs to the Air Force Shiva-Star Facility for micro-fusion experiments. The project will also continue to assess the feasibility of a total-charge-transfer cathode for high-power plasma thrusters that is an order of magnitude beyond the current state-of-the-art, and will continue to investigate the concept of a dense plasma focus thruster using aneutronic fuels. Two pulse detonation engine test articles have been constructed and have begun initial tests to demonstrate the engineering feasibility of rocket engines based on this promising technology. Short track tests of a magnetic levitation breadboard were conducted to investigate its potential application for launch assist. Free-flight tests of a laser-powered launch vehicle were conducted using a ground-based laser on a small test article.

In FY 1999, the Space Transportation Research projects will pursue proof-of-concept research in technology areas that may lead to significant reductions in the cost of access to space or may enable new space missions. The testing activities associated with the pulse detonation rocket engines and the magnetic levitation breadboard will be transferred to the Small Payload Focused program for the next phase of testing. Exotic fuels research on strained ring hydrocarbons, initiated jointly with NASA GRC and the Air Force Research Lab at Edwards, will test fire several high-performance hydrocarbons in a small rocket motor. Solid hydrogen experiments will continue at GRC, aimed at controlling high-energy-density fuels based on atomic recombination energy. Experiments and analyses will continue on very advanced, high-power electric thrusters and advanced energy concepts. The antimatter-triggered fusion research will continue toward the eventual objective of acquisition, storage, and experimentation.

Analyses and experiments will be performed to determine the feasibility of some potential fusion propulsion concepts. Safe, low-cost nuclear propulsion concepts will continue to be analyzed and some experiments, without nuclear material, will be conducted to evaluate potential performance enhancements. Analyses will continue to investigate avenues for interstellar missions and their precursors. Proposals will be solicited and evaluated for low-cost breakthrough propulsion physics experiments.

In FY 2000, Space Transportation Research will be guided by peer review of the most promising breakthrough concepts. The first peer review was conducted in FY 1998 and recommended focusing Space Transportation Research on advanced high-energy-density fuels, antimatter concepts and other breakthrough propulsion physics. Space Transportation Research will continue to pursue propulsion concepts that have the potential for interstellar travel.

Engineering Capability Development continues to fund utilization, maintenance, and productivity upgrades for the premiere national facilities at LaRC, GRC and ARC required to accomplish the goals of ASTP and RLV. FY 2000 funding for this effort will be shared by multiple programs.